Energetic Particle Propagation and Acceleration from the Low Corona and through the Solar System

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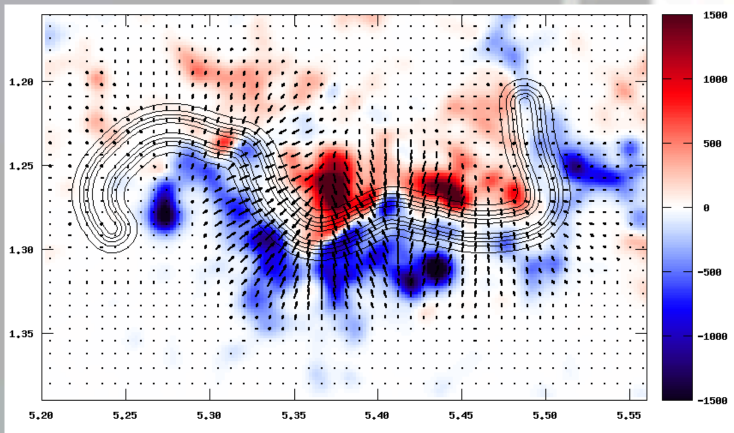
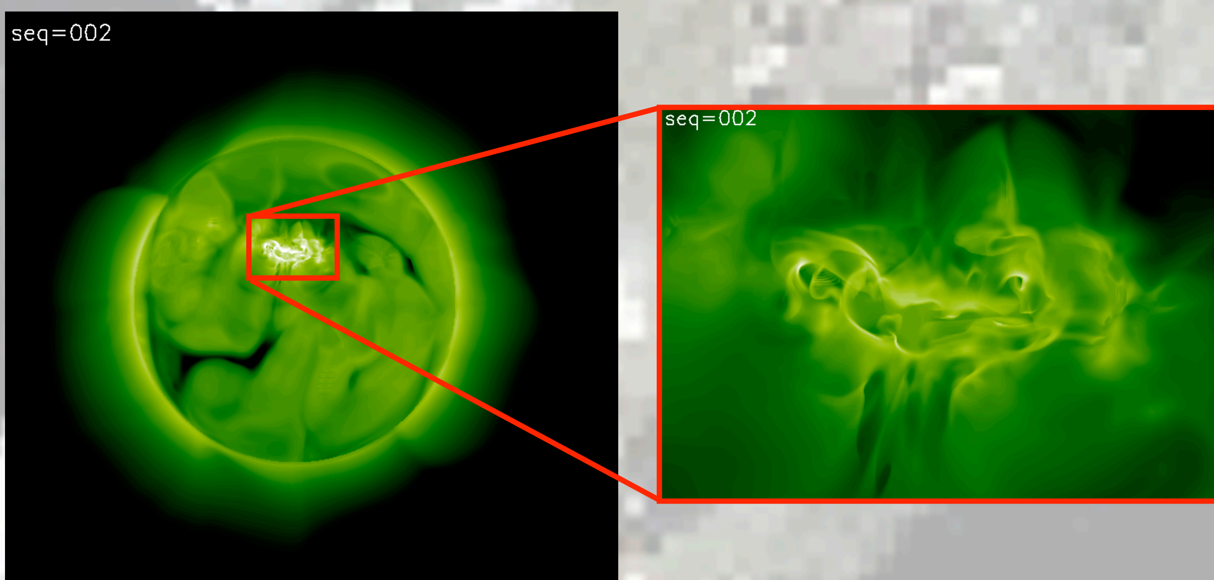
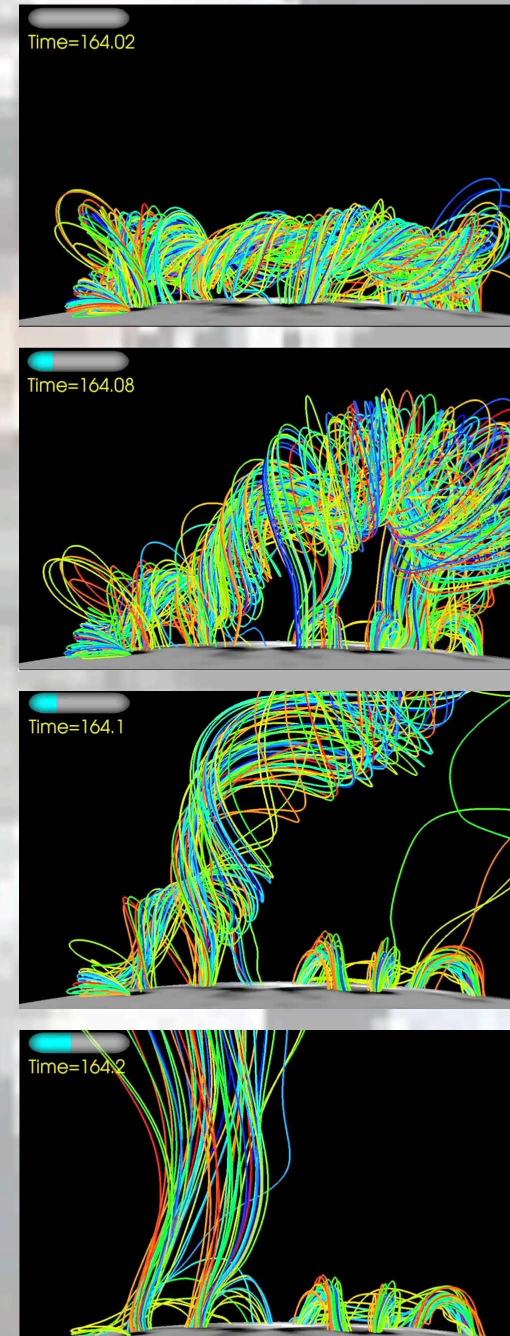
Eruption

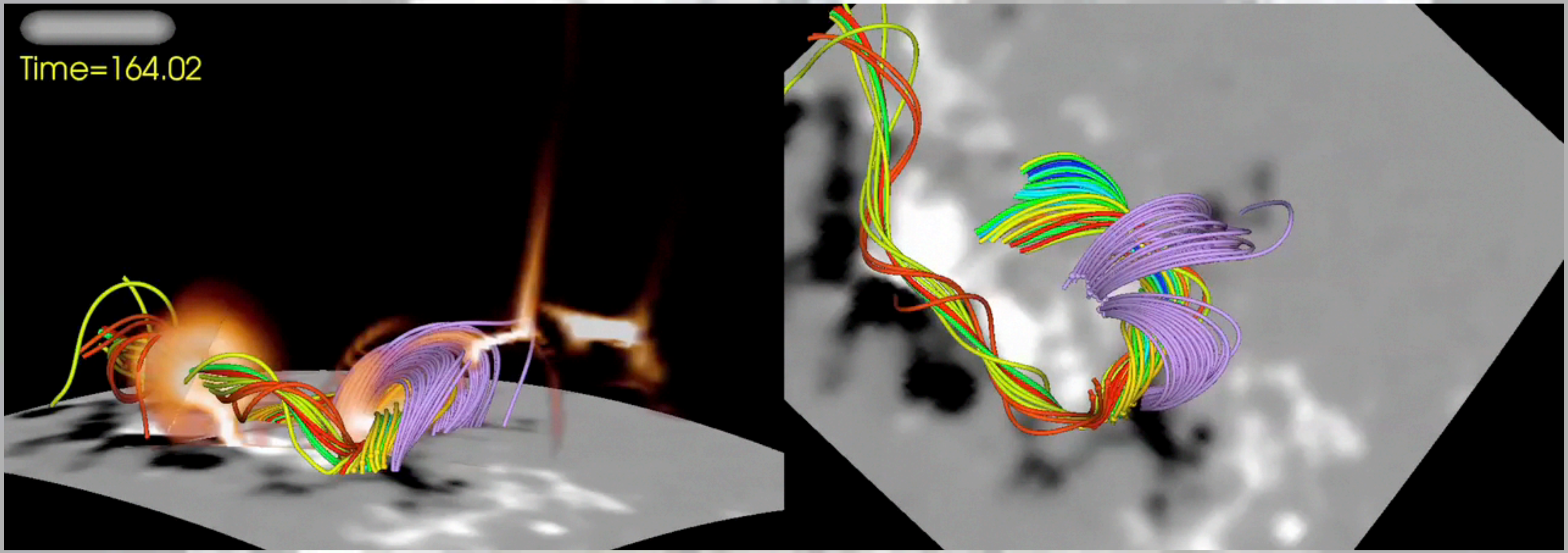


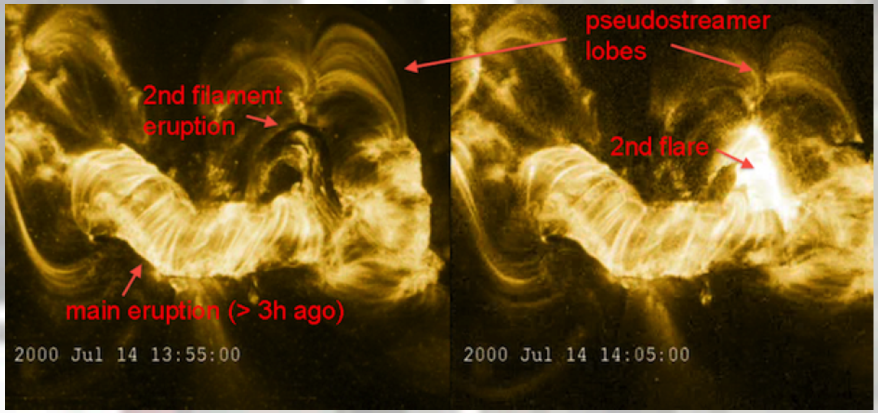
- *Flux rope eruption triggered by localized converging flows*
- *Eruption evolves west to east as was observed*

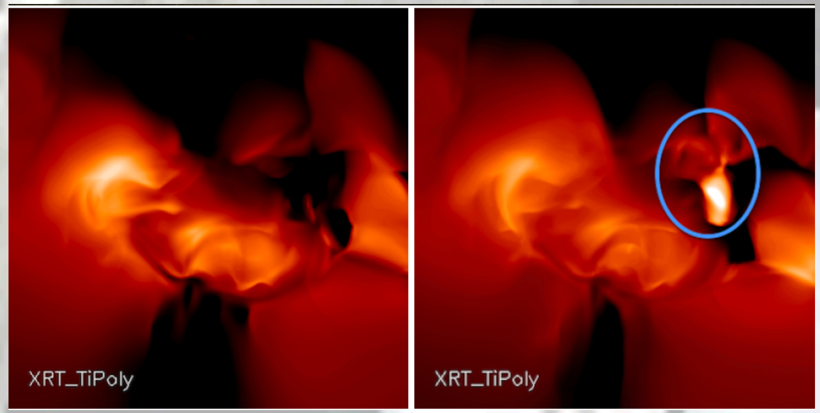




Sympathetic eruption

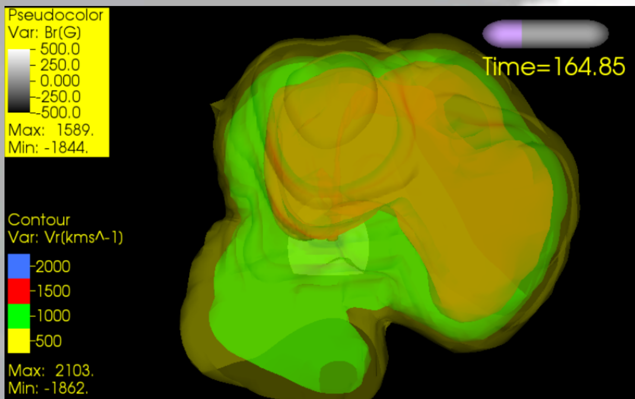


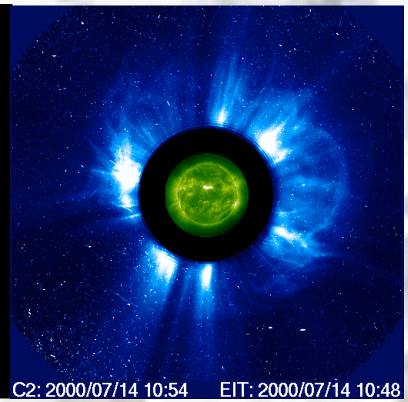


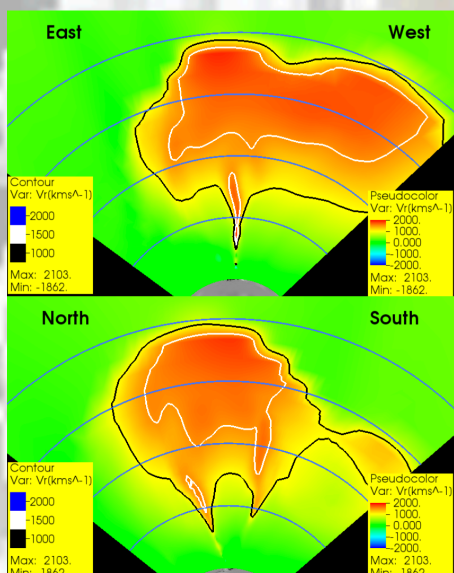


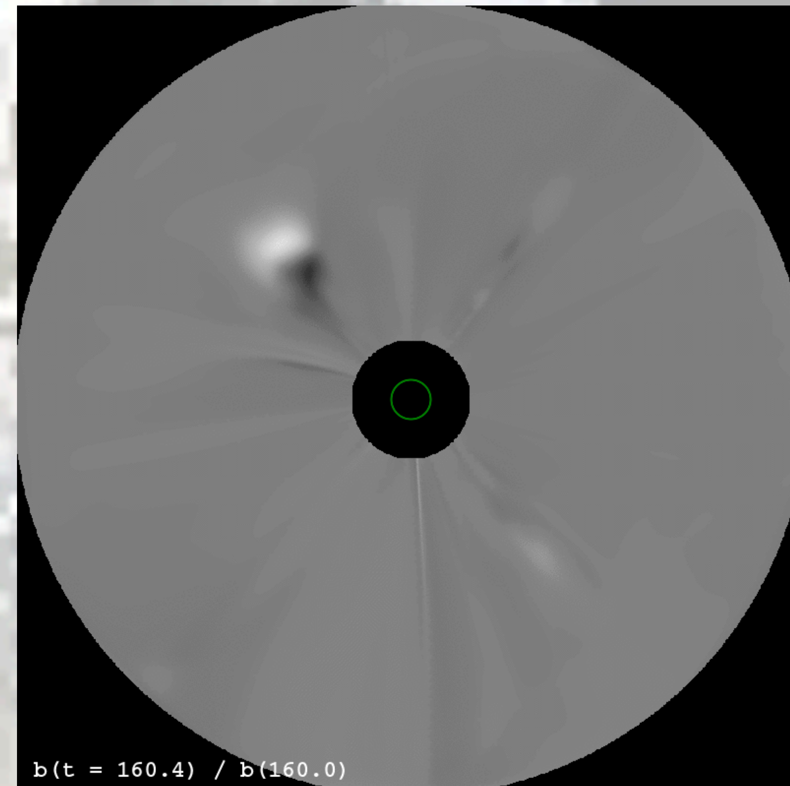
- *Second eruption qualitatively reproduced*

CME propagation





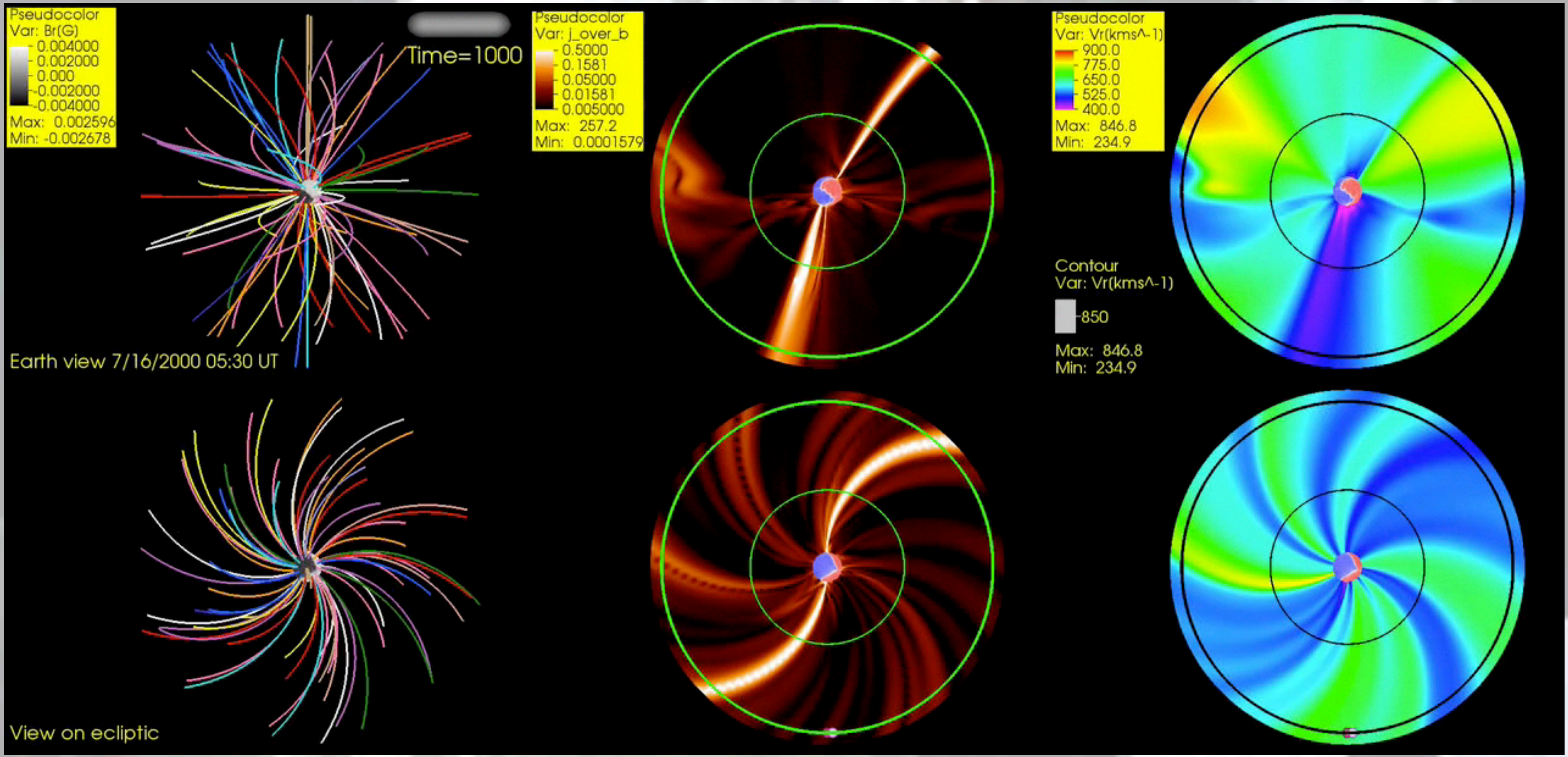




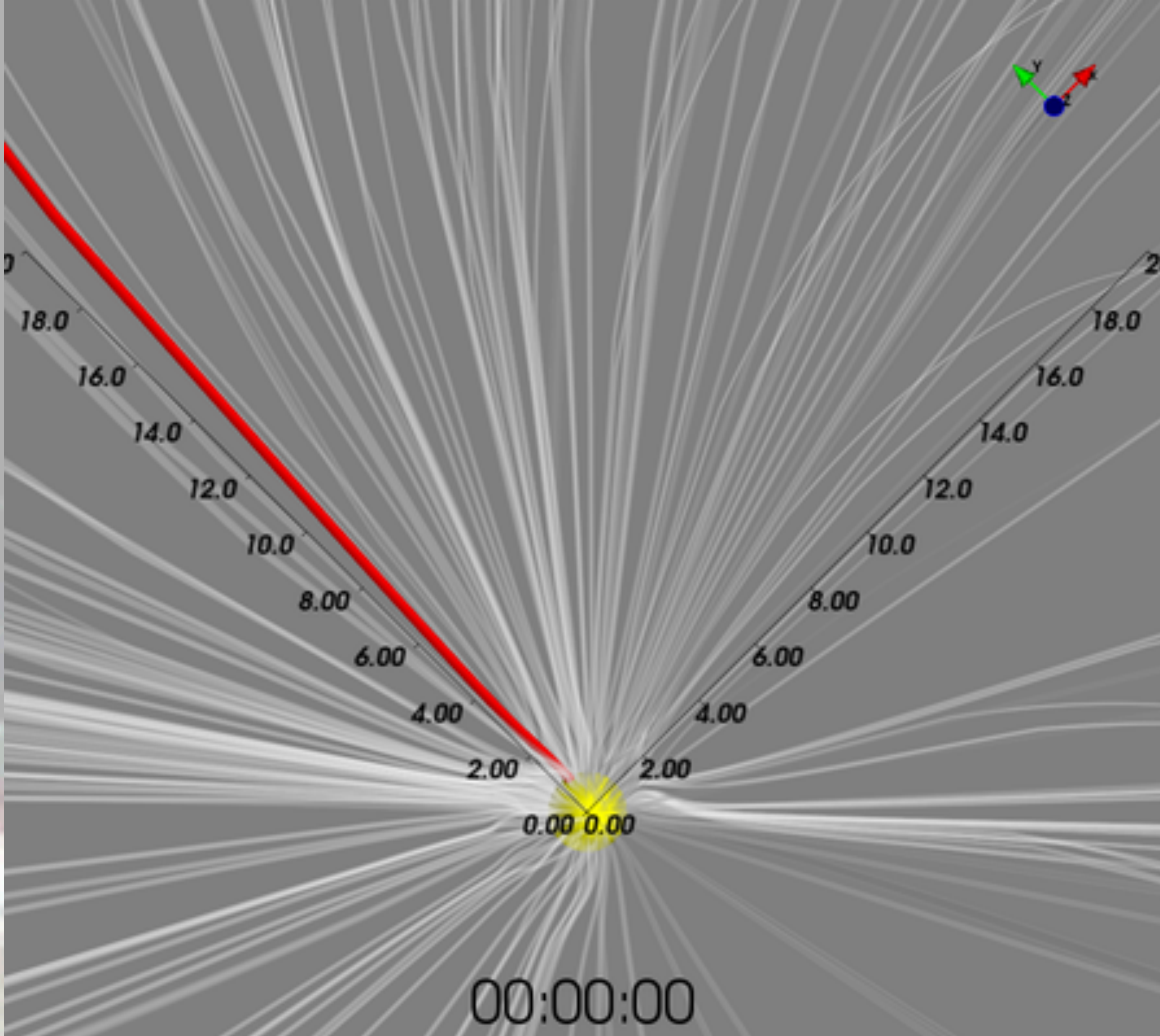
Halo CME
(Brightness as running ratio)

- *CME kinetic energy = 4x10^{32} ergs*
- *CME propagation speed $\gtrsim$ 1500 km/s*

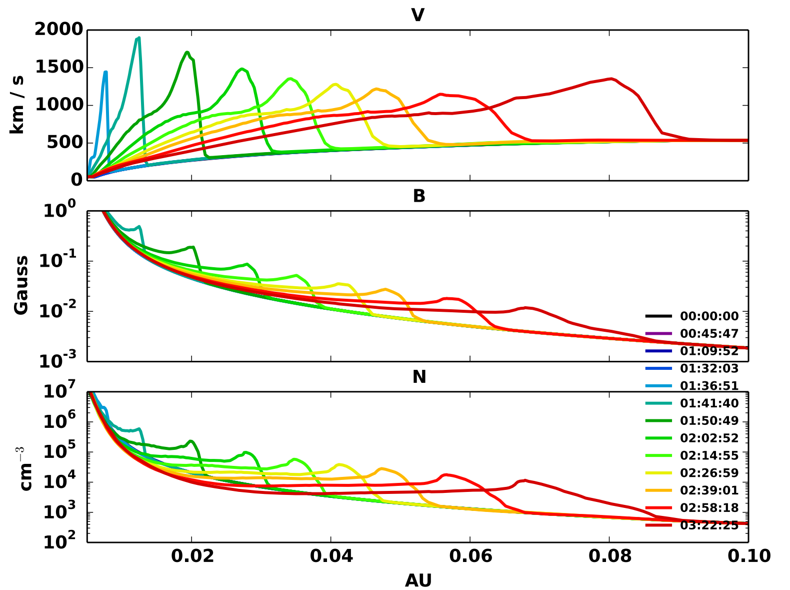
Interplanetary propagation



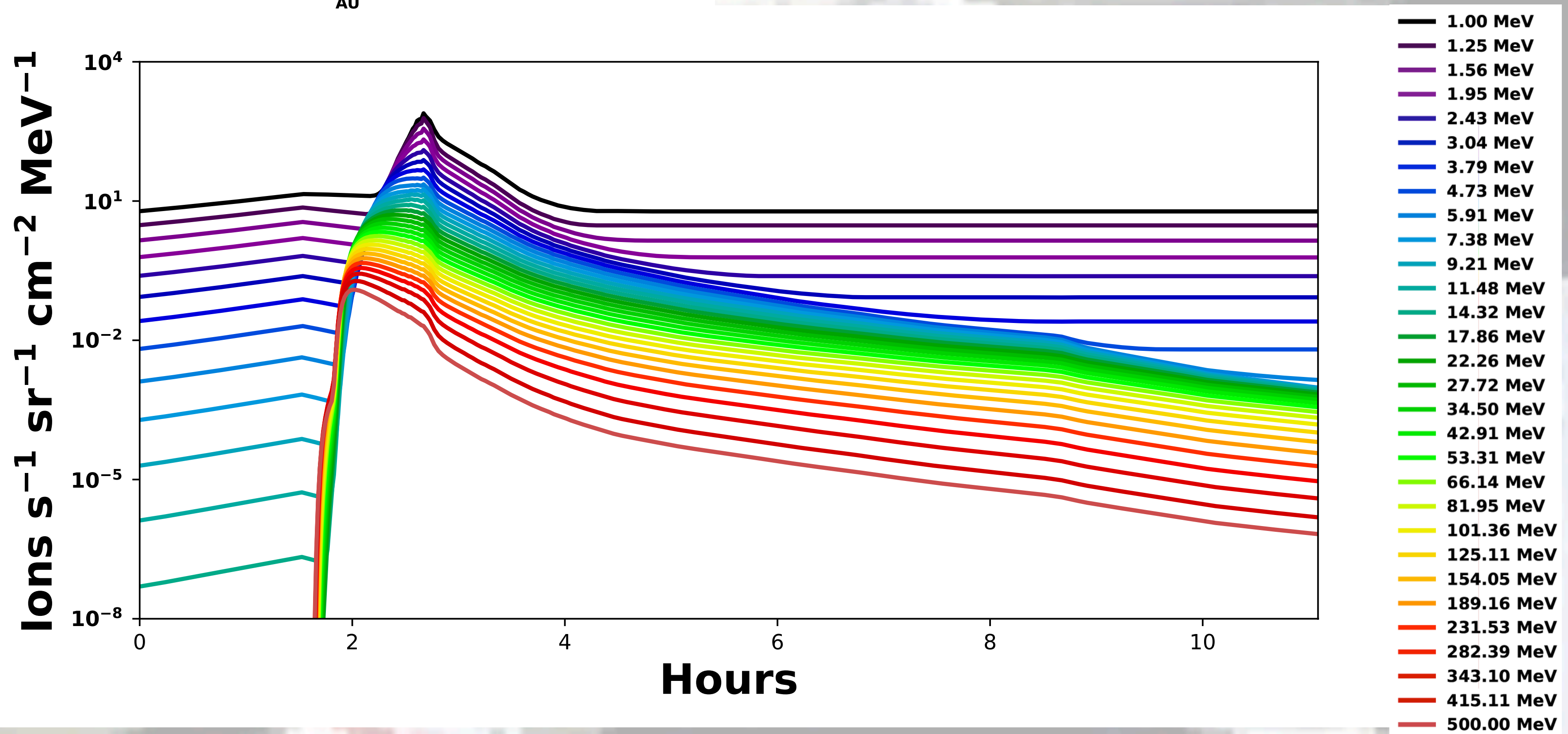
- *Simulate the propagation of the CME to 1 AU*
- *Coupling to heliospheric code in rotating frame (Lionello et al. ApJ 2013)*



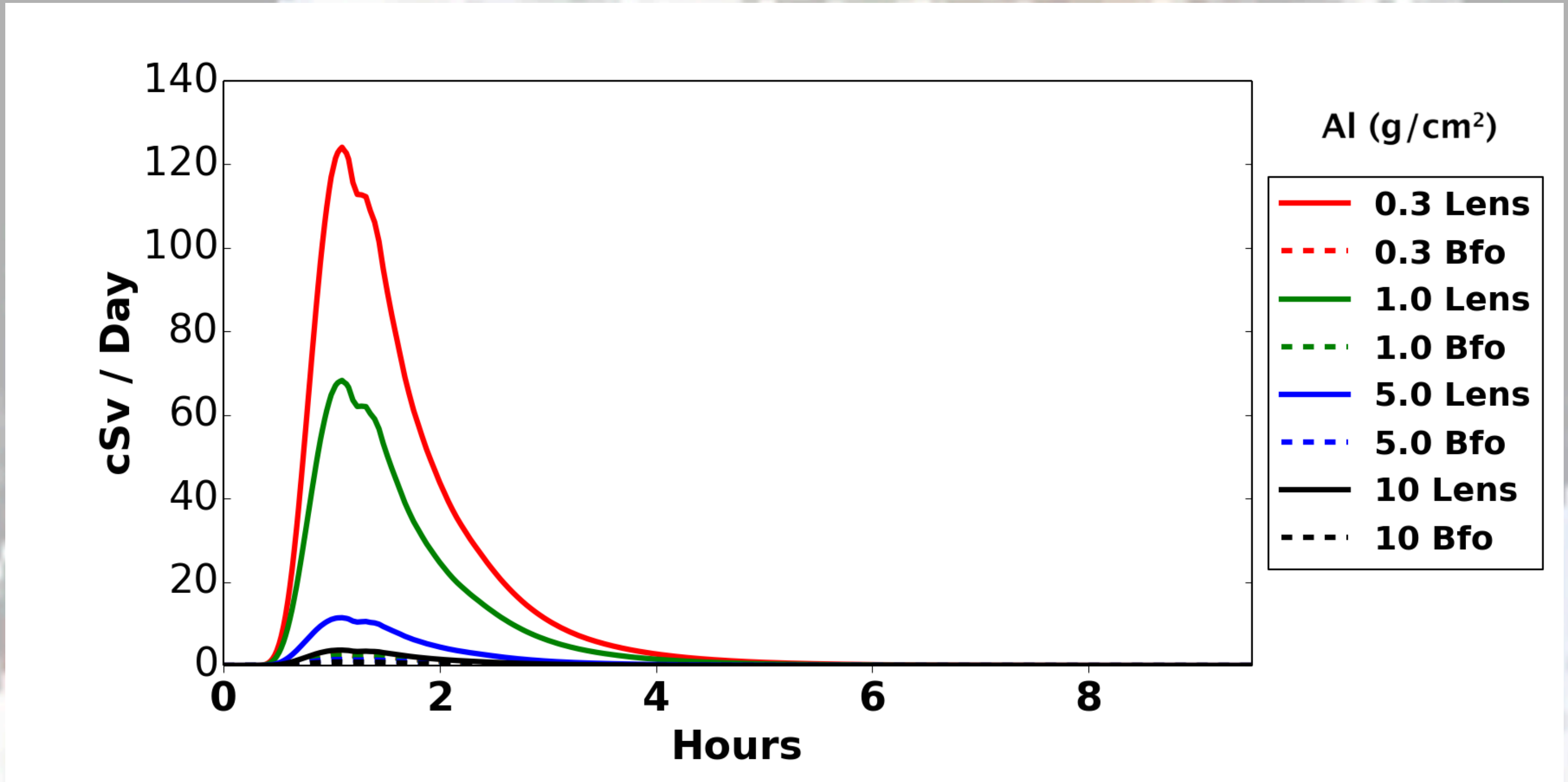
18.0
16.0
14.0
12.0
10.0
8.00
6.00
4.00
2.00
0.00
0.00
2.00
4.00
6.00
8.00
10.0
12.0
14.0
16.0
18.0
20
00:00:00


V
km / s
2000
1500
1000
500
0
B
Gauss
10^0
10^-1
10^-2
10^-3
N
cm^-3
10^7
10^6
10^5
10^4
10^3
10^2
0.02
0.04
0.06
0.08
0.10
AU
00:00:00
00:45:47
01:09:52
01:32:03
01:36:51
01:41:40
01:50:49
02:02:52
02:14:55
02:26:59
02:39:01
02:58:18
03:22:25


10 Solar Radii


Ions s^-1 sr^-1 cm^-2 MeV^-1
10^4
10^1
10^-2
10^-5
10^-8
0
2
4
6
8
10
Hours
1.00 MeV
1.25 MeV
1.56 MeV
1.95 MeV
2.43 MeV
3.04 MeV
3.79 MeV
4.73 MeV
5.91 MeV
7.38 MeV
9.21 MeV
11.48 MeV
14.32 MeV
17.86 MeV
22.26 MeV
27.72 MeV
34.50 MeV
42.91 MeV
53.31 MeV
66.14 MeV
81.95 MeV
101.36 MeV
125.11 MeV
154.05 MeV
189.16 MeV
231.53 MeV
282.39 MeV
343.10 MeV
415.11 MeV
500.00 MeV

Dose Rates from Event

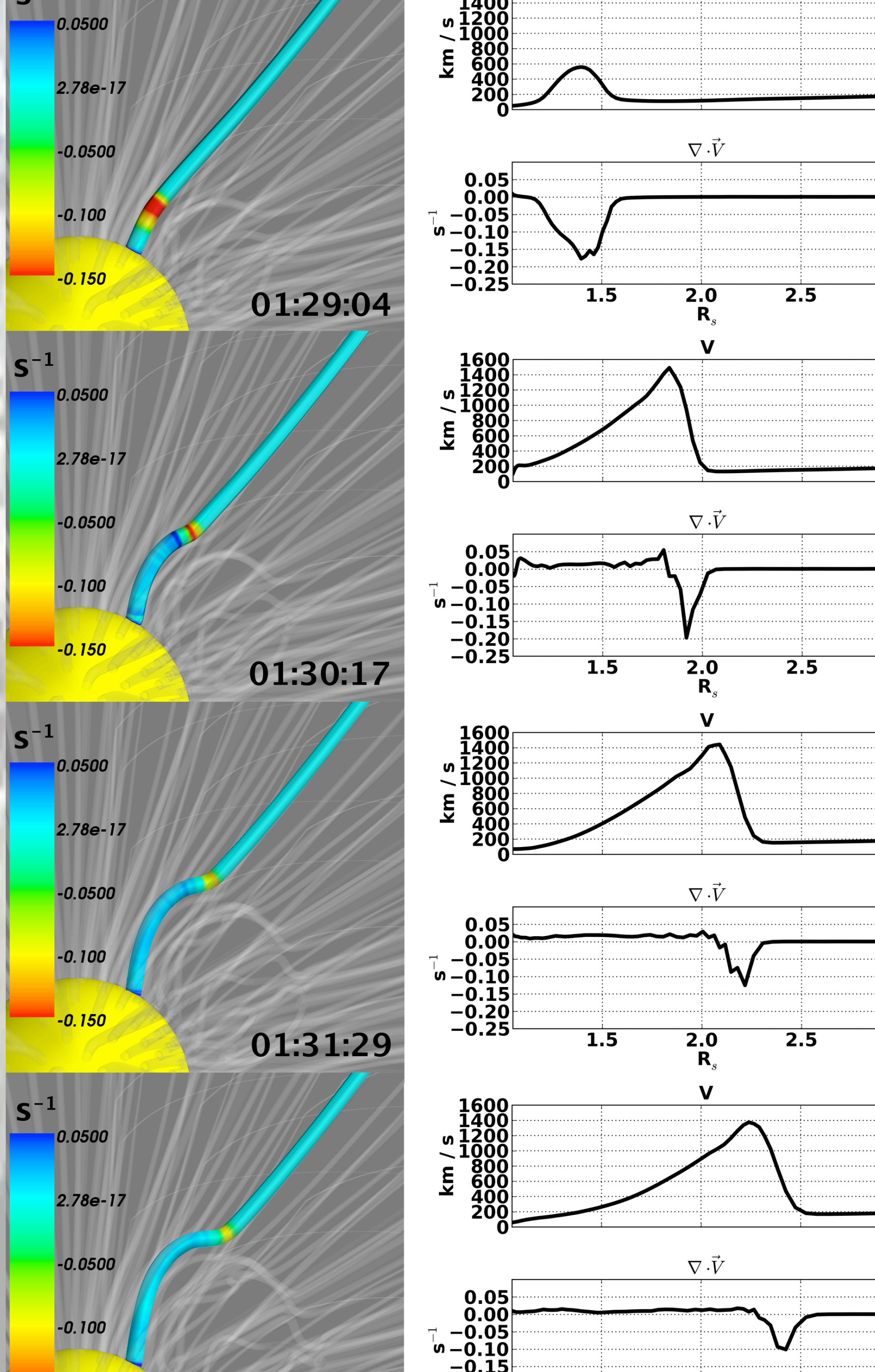


Localized acceleration in low corona

- In Parker-transport (assuming near isotropy), all particle acceleration arises from velocity divergence:

$$\frac{\partial f}{\partial t} + \boldsymbol{u} \cdot \nabla f - \nabla \cdot (\mathsf{K} \cdot \nabla f) - \frac{\nabla \cdot \boldsymbol{u}}{3} p \frac{\partial f}{\partial p} = Q_0 \delta(x) \delta(z) \delta(p - p_{\text{inj}}),$$

Schwadron et al., 2015



Diffusive solution with and without escape

- Assumes 70° shock-normal

$$\lambda_{\|} = \lambda_{\|0}(R_g/R_{g0})^{\chi}$$

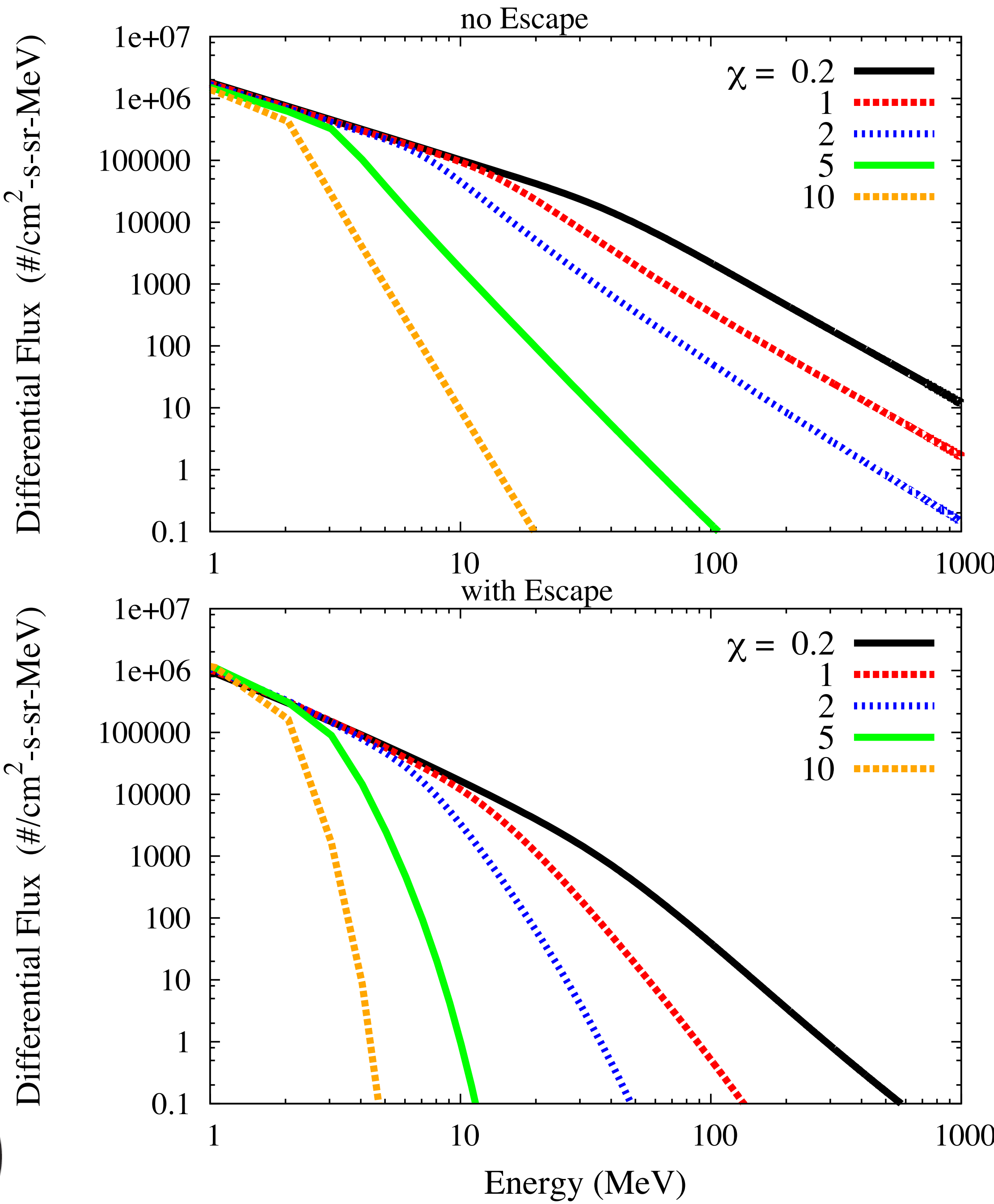
$${}_L(z,p) = \frac{3u_1}{2\Delta u} f_{\mathrm{inj}}\epsilon \left(\frac{p}{p_{inj}}\right)^{-\gamma}\left[\mathrm{erf}\left(\frac{L+z_d+z}{2\sqrt{D_z}}\right) - \mathrm{erf}\left(\frac{z_d+z}{2\sqrt{D_z}}\right)\right].$$

$$z_d = -\frac{3}{(\chi+1)\Delta u}(\kappa_{xz1}+\kappa_{xz2})$$

$$D_z = \frac{3}{2(\chi+1)\Delta u}\sum_{j=1}^{2}\left\{\frac{\kappa_{\|}\kappa_{\perp}}{u_{xj}} + \frac{(\kappa_{xzj})^2}{u_{xj}}\right\}$$

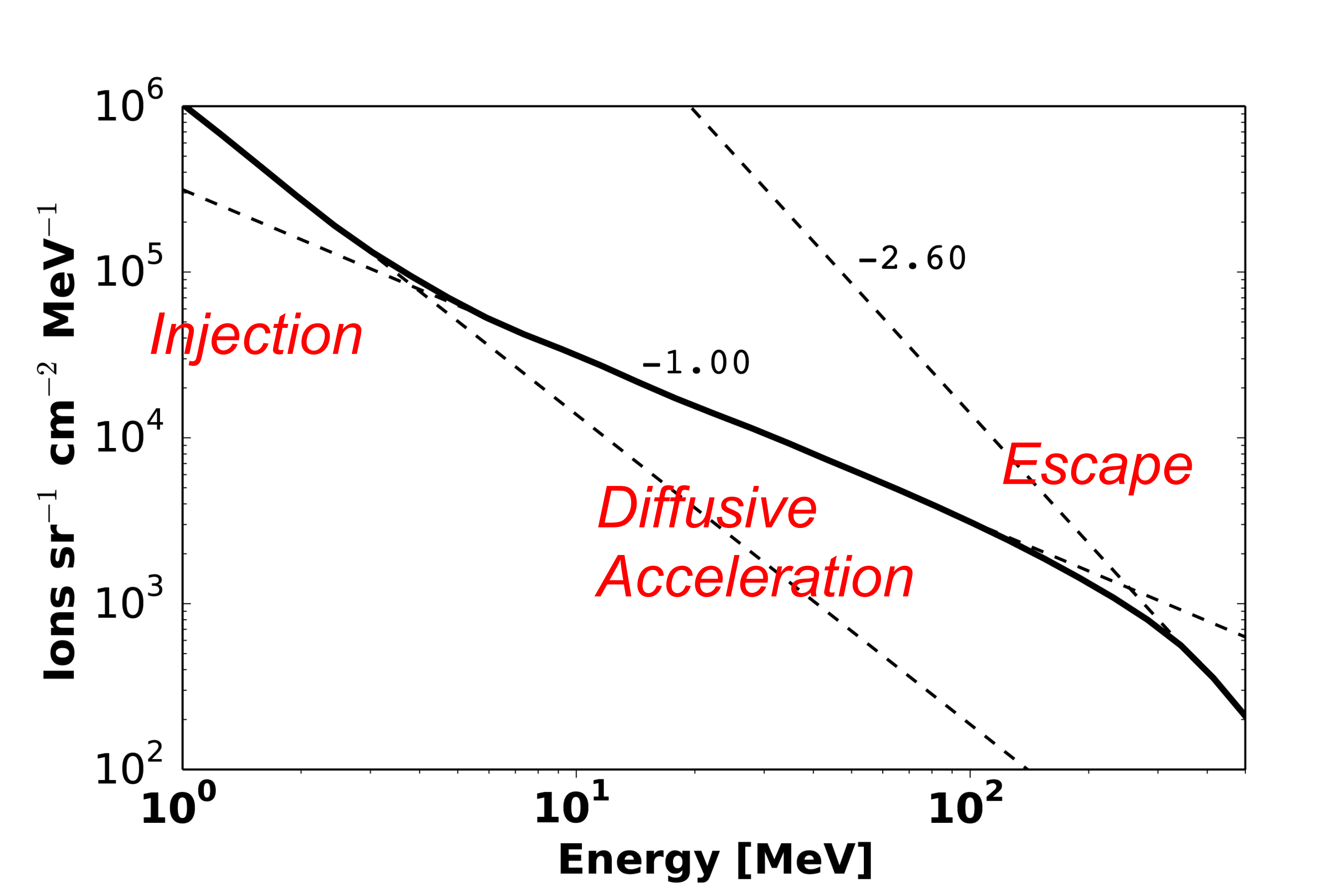
$$F_L^{\mathrm{escape}}(z,p) = F_L(z,p)\,g^{\mathrm{escape}}(p)$$

$$g^{\mathrm{escape}}(p) \approx \exp\left(-\frac{6}{(\chi+1)\Delta u}\sum_{j=1}^{2}\sqrt{\frac{\kappa_{xzj}}{\tau}}\left[1-\left(\frac{v_{\mathrm{inj}}}{v}\right)^{(\chi+1)/2}\right]\right)$$

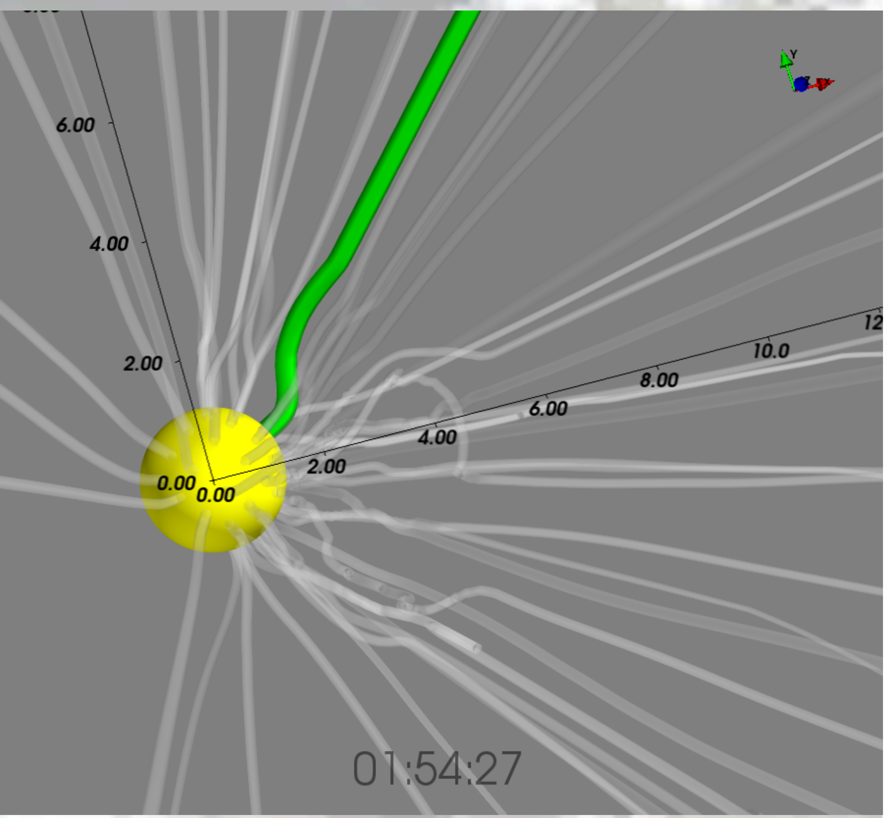


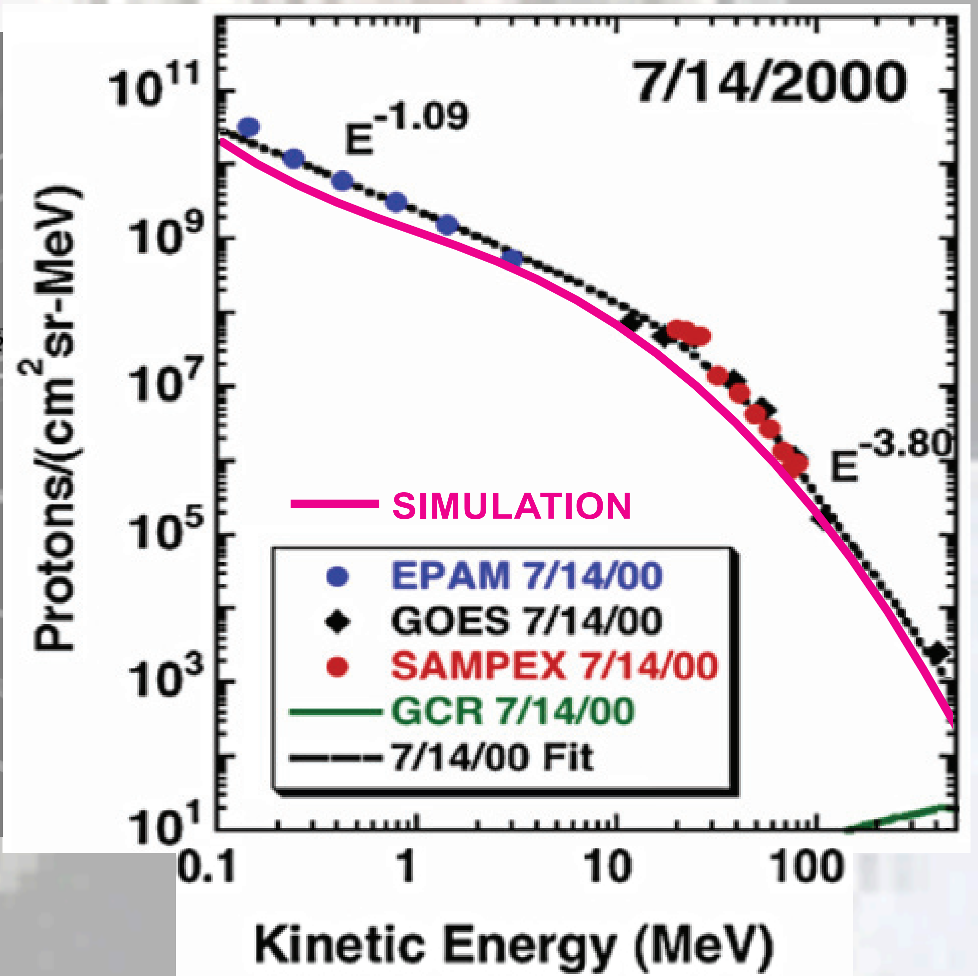
Schwadron et al., 2015

Decomposing Event

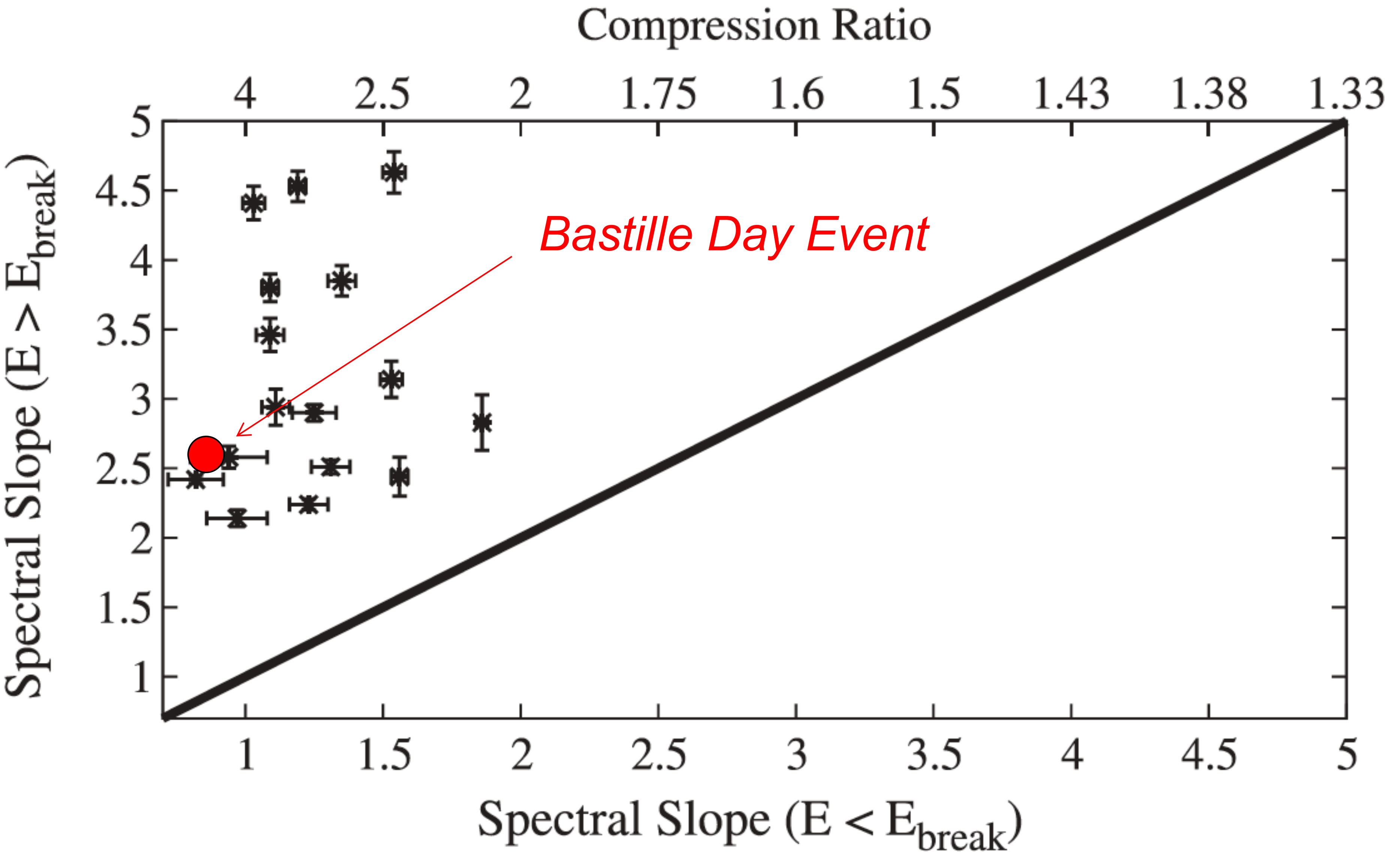


Flank Acceleration and Observational Comparison





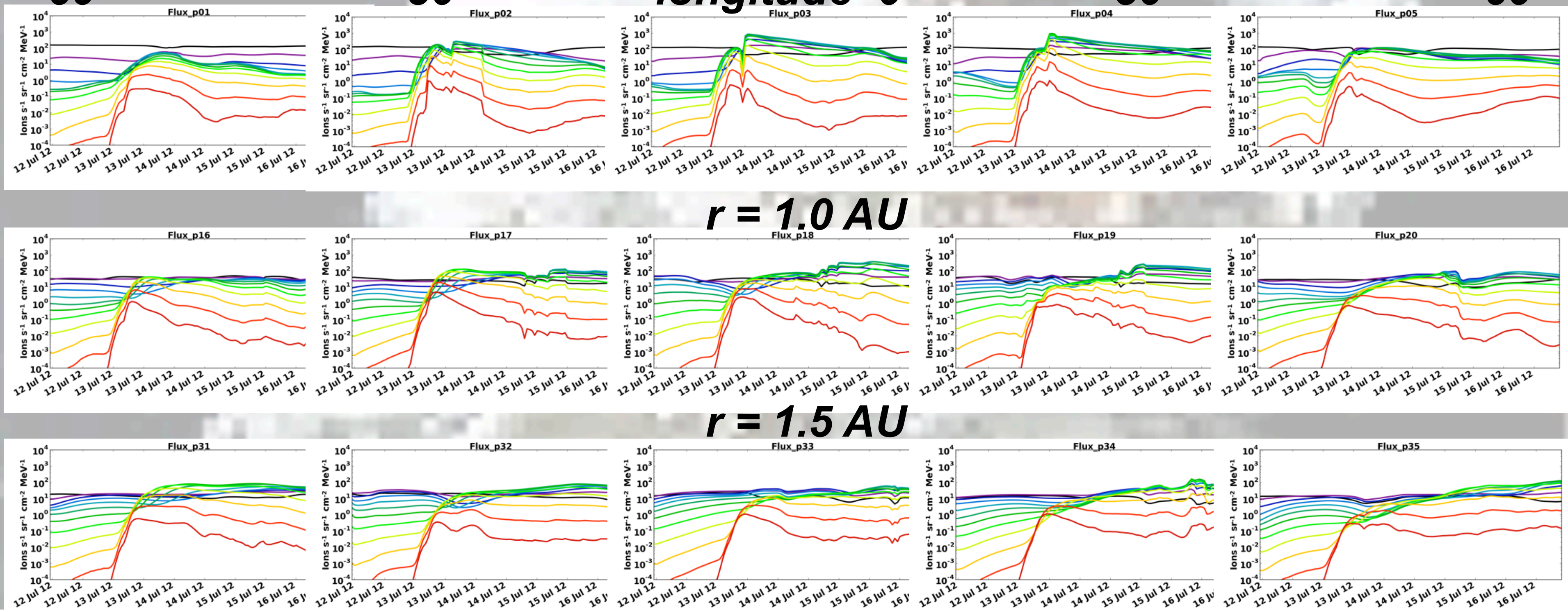
Flank Acceleration GLEs

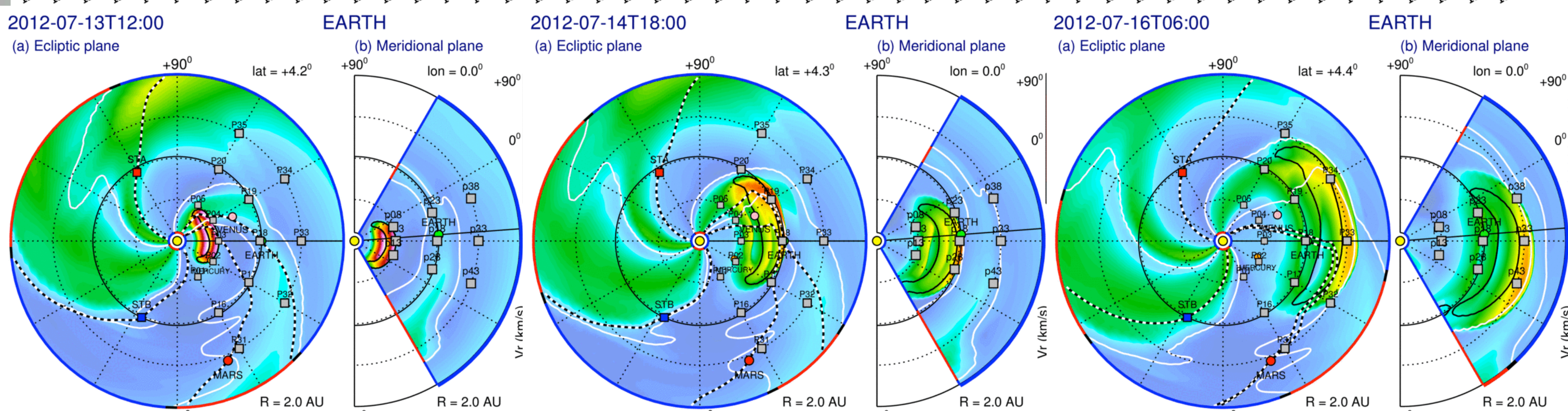


EPREM SEP profiles at different observers (latitude=0°)

east *west*

-60° **-30°** ***r = 0.5 AU*** ***longitude=0°*** **30°** **60°**

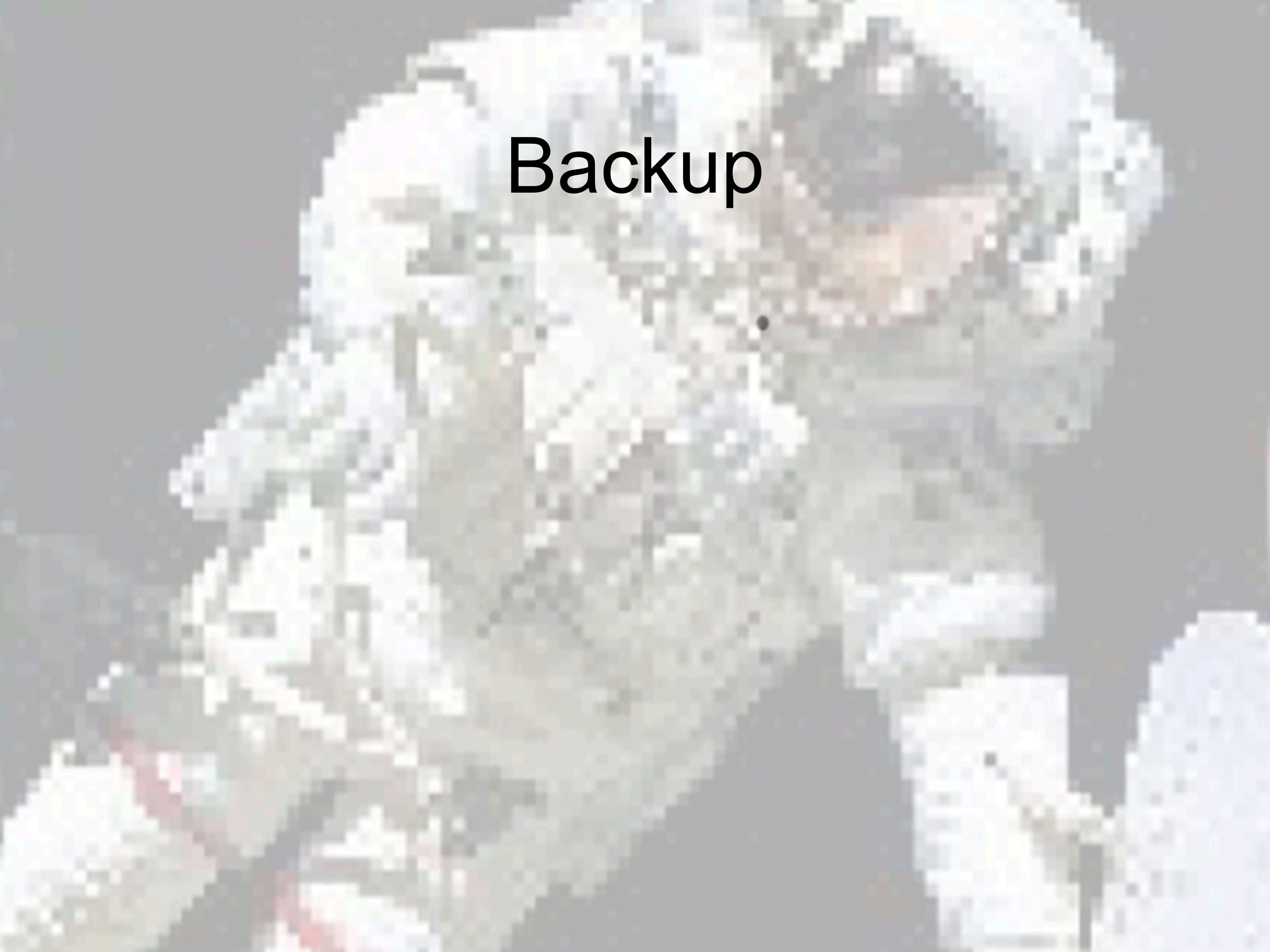




Conclusions

- Discovering roots of Energetic Particle Acceleration in Low Corona
- Significantly broadens longitudinal spread
- Characteristic spectrum showing
  - Injection
  - Diffusive flank acceleraion
  - Escape at high energies
- Validation both via time profiles and spectral shape of event

Backup



C-SWEPA Goals

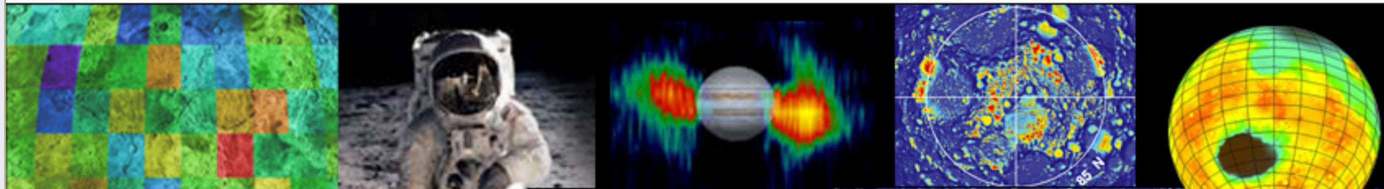
- **Goal 1:** Scientifically explore the seed populations and acceleration of energetic particles in the low corona, through interplanetary space, and over broad longitudinal regions
- **Goal 2:** Couple the energetic particle acceleration model (EPREM, the energetic particle radiation environment model) with MHD models that describe the propagation of coronal mass ejections from the low coronal plasma environment through the interplanetary medium.
- **Goal 3:** Validate results the coupled EPREM and EMMREM models with observations at distributed observers near 1 AU and out beyond Mars. Validation extends across our understanding of radiation induced hazards from solar energetic particles and galactic cosmic rays at Earth down to atmospheric levels, out into deep space and to Mars and beyond.
- **Goal 4:** Extend key data sets useful for the project: shock parameters at 1 AU, CME propagation data, and radiation environment data through the inner heliosphere.

C-SWEPA Role – National & International Teams

- The Cosmic Ray Telescope the for the Effect of Radiation (CRaTER) team (http://crater.unh.edu)
- The Dynamic Response of the Environments at Asteroids, the Moon, and the Moons of Mars (DREAM and DREAM2 Projects, http://ssed.gsfc.nasa.gov/dream/)
- The Sun-2-Ice team (http://sun-2-ice.sr.unh.edu, NSF FESD)
- The Solar Probe Plus team *(http://solarprobe.jhuapl.edu)*
- The International Team on Radiation Interactions. (http://www.issibern.ch/teams/interactplanetbody/)

INTERNATIONAL SPACE SCIENCE INSTITUTE

ISSI Research Team:
Radiation Interactions at Planetary Bodies



The Internatioinal Space Science Institute (ISSI) is an Institute of Advanced Study, bringing together scientists from all over the world meet in a multi- and interdisciplinary setting to advance the understanding of results from space missions, ground based observations and laboratory experiments.

The international research teams are set up in response to an Annual Call by ISSI. Their goal is to carry out a resarch project leading to publications in scientific journals.

Proposal Abstract

Radiation Interactions at Planetary Bodies

SINCE THE LAUNCH of the Lunar Reconnaissance Orbiter (LRO) in 2009, the Comic Ray Telescope for the Effects of Radiation (CRaTER) has directly measured the Lunar radiation environment and mapped albedo protons (~100 MeV) coming from the Moon. Particle radiation has widespread effects on the lunar regolith ranging from chemical alteration of lunar volatiles to the formation of subsurface electric fields with the potential to cause dielectric breakdown that could modify the regolith in permanently shaded craters. LRO/CRaTER's direct measurements are transforming our understanding of the lunar radiation environment and its effects on the moon.

Similarly, the Radiation Assessment Detector (RAD) has been measuring the energetic particle radiation environment on the surface of Mars since the landing of the Curiosity rover in August 2012. The Martialn surface is protected by the atmosphere above; though only about 1% as thick as Earth's, its depth is sufficient to stop solar wind ions and the large majority of Solar Energetic Particles. RAD, like CRaTER, measures radiation dose, dose equivalent (related to human health risks), and particle spectra to enable rigorous tests of environment and transport models.

Recent measurements of galactic cosmic radiation and solar energetic particle radiation at other planetary objects (e.g., the moons of Mars) raise new fundamental questions about how radiation interacts at planetary bodies and what its long term impacts are.

This ISSI team will advance the study of radiation interactions.
Read more... (proposal and abstract, pdf)